GIS DATA MAINTENANCE AND MANAGEMENT WITH SPATIOTEMPORAL MODEL

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ABSTRACT:

Recently, GIS related research and applications have been making rapid progress. Computers with faster CPU and larger memory enable practical applications of time consuming and memory intensive algorithms, both for spatial analysis and visualization. Storage devices become cheaper and have larger space to store data of larger volume and more varieties including image, sound and video. For GIS data capture, novel technologies such as GPS, laser range finder, synthesize aperture radar are getting more and more popular, which bring us terrain data of higher precision at lower cost. Yet, our living environment is also changing rapidly, which makes it a task of high cost and complexity to maintain and manage geometric data such as cartographic or utility information. This paper proposes a system for efficient GIS data maintenance and management. It makes use of a spatiotemporal data model for describing various types of dynamic changes of GIS data, manipulating data in multidimensional space including time. The experiments performed on the initial implementation of the proposed system show its ability of efficient and accurate maintenance of dynamic GIS data.

1. INTRODUCTION

Recently, GIS related research and applications have been making rapid progress. Algorithms for spatial access of GIS data has been thoroughly studied and put into practical use(Rigaux 2002).Computers with faster CPU and larger memory enable practical applications of time consuming and memory intensive algorithms, both for spatial analysis and visualization. Storage devices become cheaper and have larger space to store data of larger volume and more varieties including image, sound and video. For GIS data capture, novel technologies such as GPS, laser range finder, synthesized aperture radar (SAR) are getting more and more popular, which bring us terrain data of higher precision at lower cost (Lu 2001). Yet, our living environment is also changing rapidly, which makes it a task of high cost and complexity to update the initial data, especially those such as cartographic or utility information, of a GIS system according to the latest changes, because of the complexity in spatiotemporal changes.

The active study of GIS in the spatiotemporal aspect has a history of only less than 10 years (Al-Taha 1994, Castagneri 1998, Yuan 1996, Ott 2000). Therefore even though many practical models have been proposed and are adopted in various types of practical systems, there are still very few commercial systems that offer handy processing abilities for time-integrated applications. Furthermore, the up to date researches related to spatiotemporal issues all emphasize on description of dynamic GIS data.

This paper proposes a system for efficient GIS data maintenance and management. It makes use of a spatiotemporal data model for describing various types of dynamic changes of GIS data, manipulating data in multidimensional space including time. The system not only has the ability of spatiotemporal representation and manipulation, but also enables distributed data updating, detection of spatiotemporal errors during data updating. The experiments performed on the initial implementation of the proposed system show its ability of efficient and accurate maintenance of dynamic GIS data.

2. THE SPATIOTEMPORAL DATA MODEL

2.1 The Data Schema

The spatiotemporal data model is based on the spatio-temporal object model proposed in the spatiotemporal GIS DiMSIS [kakumoto 1997, Hatayama(a) 2001], which adopts an implicit destription and calculation data model. In this model, all the geoemtric objects are described by elements of polyline (vector) and point (connector), each having a tuple of time factors as follows:

$$\text{Time} ::= \{ GS, GE, ES, EE \}$$

where, G stands for generation, E extinction, S start and E end respectively. Fig. 1 illustrates the concept of time tuple, which enables the description of the chaning process of an spatial object, from the beginning of generation, end of generation, beginning of extinction to end of extinction.

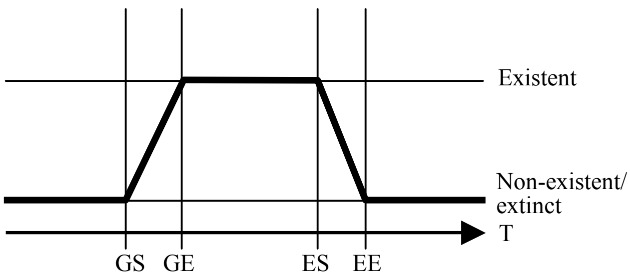

Fig.1 The concept of time tuple

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This model is "implicit" since it has no duplicated vectors. Face objects are described by a representitive point (connector) locationed inside it. The actual boundary data of the face will be extracted from the related connector whenever necessary.
Fig.2 illustrates an example of description for dynamic spatial object with the above data model. The polylines between intersections are represented as vectors. The faces such as cadastral boundary, building shape etc are represented by connectors inside them. The value of time is represented by the nubmer of days since the initial setting time of the database.
The changes of spatial objects are recorded by their related vectors and connectors with appropriate time values. In this case, the boundary of a land is represented in dashed line. It used to have a single building before the time 1003. But after the time 1003, the land was divided into two parts, and the old building was replace by two seperate smaller buildings. The faces of old boundary and the new ones are represented by three connectors with the appropriately set time tuple. Since the boundary in dashed line and its corresponding new boundaries overlap with each other, only the dashed line is drawn here. We can notice that the chang of boundary are not simply by deletion of the data, but by modification of the extinction time. In this way, the temporal event/history can be maintained with much fewer overhead than models such as time slice or space-time composite.

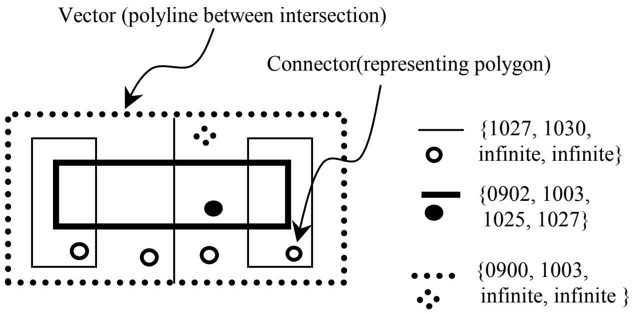


Fig.2 Dynamic object descrition with implicit spatiotempral model

Among the attributes of vector and connector, there is the relation connector, which indicates inheritance, include and group relationship with other objects. Each connector can also store a text key of varible length for recording necessary informatino, such as address, statistical value, the index to an relational database.

2.2 The Description Ability of Spatiotemporal Events

With the above data mode, we can implemented the following descriptors for spatiotemporal events

a. predecessor/successor
this can be realized by insertion of connectors with the relation attribute
b. discrete change
this can be realized by setting GS, GE, ES and EE to the same specified time, in combination of predecessor and successor descriptions
c. stepwise change,
this can be realized by setting GS, GE, ES and EE
d. continuous change (linear)
this can be realized in the same way as stepwise with the temporal interpolation algorithms[Zhang 1999]

2.3 The Spatiotemporal Operations

With the same data model, we can implemented the following spatiotemporal operators:
record event of generation, by setting GS and GE respectively (ES and EE are infinite)

a. record event of extinction
this can be realized by setting ES and EE respectively
b. record event of discrete modification
this can be realized by the combination of recording event of extinction of old object and generation of the modification object.
c. retrieve objects existent in the specified duration
d. retrieve objects existent before/after an specified time
e. retrieve objects extinguished/modified in the specified duration
f. generate the temporal order of a serious of objects

3. The MAINTENANCE SYSTEM FOR DYNAMIC GIS

The main purposes of this system are:

a. Reduction of the overhead of data maintenance history
The traditional maintenance systems only keep versions (snap shots) of certain interval. Management of these versions cost more resource and sometimes cause confusions.
b. Real time updating
For applications such as those in tax related department, the actual update of real estate can only be performed once in a year. The traditional maintenance system is only feasible when all of the spatial changes during this period are collected, which will inevitably increase the work load of the maintenance department and generate a time lag.
c. Improvement of data quality
In traditional data maintenance systems, it is difficult to keep track of the changes during data updating. As a result, careless mistakes, data contradictions are hard to avoid, and consequently, it cost more to maintain data quality.
d. Spatiotemporal analysis
Since traditional data maintenance systems can only offer snap shots, spatiotemporal analysis that requires temporal events during the snap shots are impossible.

The details of this system will be presented in the following sections.

3.1 System Configuration

We have implemented a prototype system for data maintenance with the spatiotemporal data model described in section 2. The system configuration is shown in Fig. 3. The system consists of two main components: the kernel for fundamental processing and manipulation of spatiotemporal data, the graphical user interface for applications of designated specifications.
The major modules are as follows

a. Graphical user interface: offers the operator with easy to under stand menus and functions for spatiotemporal operations
b. Spatiotemporal interpreter: translates the requires from the operator into spatiotemporal descriptions
c. Spatiotemporal processing: realizes the spatiotemporal descriptions with the spatiotemporal operators

d. Error detection: find and visualization of and temporal contradiction

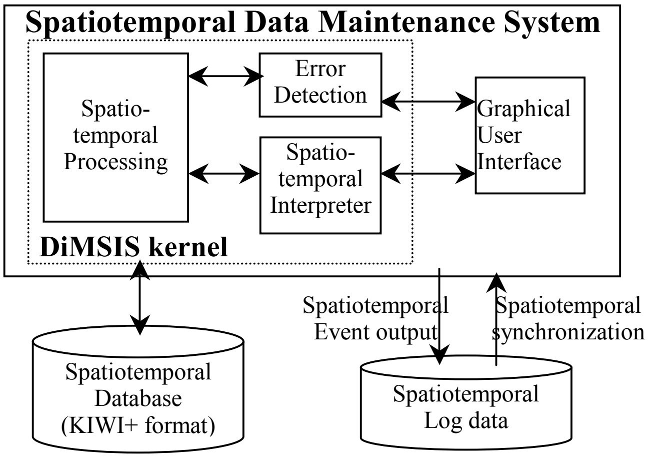


Fig.3 The system configuration

To enable distributed or real time data maintenance operations, the spatiotemporal changes can either be reflected directly into the main database, or output into a log file as spatiotemporal events, which will be imported into the main data base when necessary. This implementation also enables real time updating of the database without affecting the main database. The later case is often required by organizations such as local municipal governments, where the daily official works rely on data that are updated in certain period, typically once every year. Updating all the spatiotemporal changes at time will cause a time lag in the freshness of the database. By updating spatiotemporal changes in real time base and outputting them as spatiotemporal events, the user can achieve instant synchronization with the latest situation when the time of database update comes.

3.2 The Details of Individual Modules

3.2.1 Graphical user interface

Offers the operator with easy to understand menus and functions for spatiotemporal operations. Some of the typical functions are:

a. Creation of new spatial objects
b. Modification of existing objects
c. Temporal spatial query
d. Settings for display, modification etc.
e. Exporting and importing temporal events in the form of log files

3.2.2 Spatiotemporal interpreter

Translates the requirements from the operator into spatiotemporal descriptions. Some of the typical examples are:

a. Deletion of objects:
   - set the ES and EE of the related objects.
b. Move/Modification-of-shape:
   - set the GS and GE of the original object.
   - create a new object with GS, GE, set to ($GS_{orginal}$, GE>=$ES_{orginal}$,ES=Infinite,EE=Infinite)
c. Snap shot
   - change the display time of the system

3.2.3 Spatiotemporal processing

Realizes the spatiotemporal descriptions with the spatiotemporal operators described in section 2.3. It also includes the fundamental GIS functions such as displaying the spatial objects in zoom-in/zoom-out mode, or panning the objects, changing the display colour/style etc.

3.2.4 Error detection

This module finds and visualizes both spatial and temporal contradictions/errors. Especially while maintaining historical data in the same database can help to improve the quality of data modification, it can also cause new types of errors or contradictions because of wrong setting of time values. Some of the typical functions of error detection are:

a. Duplicated vectors
   This can be caused by both negligence of deleted vectors and wrong time setting.
b. Floating terminal
   This can be caused by both incorrect snap operation and wrong time setting.
c. Intersection of vectors
d. Incomplete face
   This can be caused by both wrong operation in polygon formation or wrong time setting for vectors that form the face.
e. Face without corresponding connector
   This can be caused by both non-existence of required connector or wrong time setting
f. Connector without corresponding face

The checking are performed in spatiotemporal space in the following procedures:

a. Retrieve all the time values $\{t_0,t_1,\ldots,t_n\}$used in the database
b. Check all the items stated above for the initial time t_0, which is usually the set up time of the database.
c. For each time $t_i(0<i<n)$, find the objects with the time satisfying GE<=t_i<=ES, and check them against those that exist by time t_i

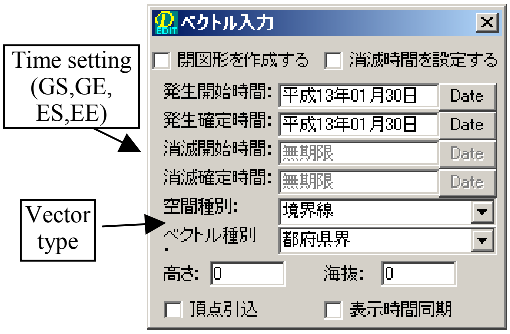
3.3 The Data Format

We have adopted KIWI+ as the data format of the system [Hatayama 2001(b)]. This format is the extension of the KIWI format under consideration as the standard of physical storage of ISO/TC204. Besides the implicit destription and calculation data model, it also enables a variety of attribute descriptions such as formated text string, symbol, relation and multimedia (attributes for presentation only; including image, vedio and sound). It also enables the asignment of the vertex of a vector as nodes for speedy searching of face from connectors. This schema can also fasten the processing of networks while maintaining precise description of their shape information.

4. The Performance Evaluation

We have implemented the system based on the specifications stated so far. The kernel part is in the form of component and the graphical user interface is application dependant and is implemented in easy to customize language.
Fig.4 shows the screen of settings for vector creation and its related time setting window.
We have performed a serious of experiments with real world data to evaluate the effectiveness of the spatiotemporal data

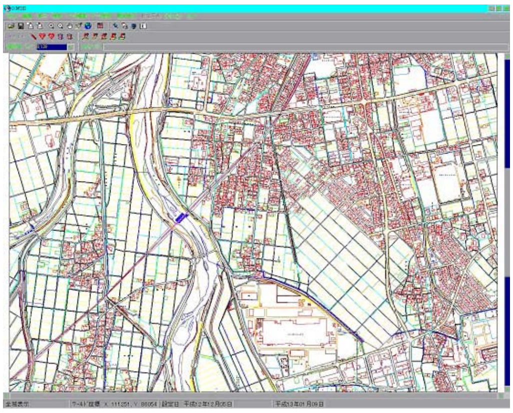
model and the operators/descriptors. Fig. 5 shows an example of spatiotemporal data modification.



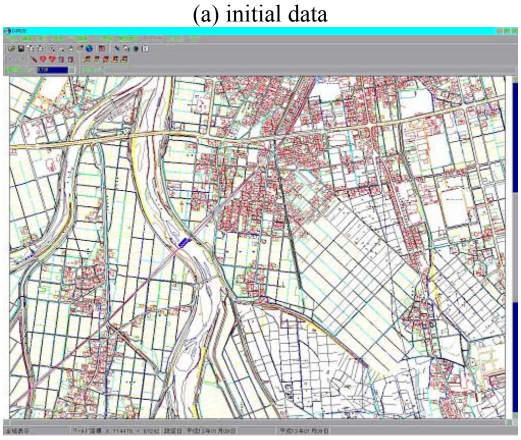
(a) Settings for vector creation

(b) time specification

Fig.4 Windows related to vector creation



(a) initial data



(b) modified data

Fig. 5 An example result of data maintenance

The results indicate the following advantages over systems of snap shot type:

a. Capability of essential spatiotemporal modification
b. Enables more intuitive data maintenance
c. Slimmer data size
d. Easier spatiotemporal data retrieval / analysis
e. High data quality with no spatiotemporal data contradictions
f. Capability of distributed data maintenance
g. Capability of data synchronization at the specified time
h. Faster reconstruction of face tracing (than older format of DiMSIS)
i.

5. Conclusions

In this paper, we have proposed a system for efficient maintenance and management of spatiotemporal data. In the initial implementation, we have only implemented modification-oriented functions. To make it easier for end users to manage the spatiotemporal database, more functions for spatiotemporal analysis are also in great demand. Further more, spatiotemporal interpolation other than linear types remains a challenge because of its complexity in scale and variety.

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